NATURAL FACTORS OF AMUR RUNOFF AND SEDIMENT DEPOSIT FORMATION

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Like many other big rivers of East Asia (Yangtze, Huang, Mekong, etc.) the Amur River carries lots of terrigenous, dissolved and organic substances into the Pacific Ocean and thus noticeably affects adjacent coastal sea waters. In XX century these rivers became main sources of various substances of anthropogenic origin, discharged into the World Ocean.

The Amur River is the biggest river system in the north-west part of the Pacific Ocean. Its annual average Amur runoff is 369.1 km^3 (Mordovin, 2001). To compare, the Azov Sea water content is about 300 km^3. 263.6 km^3 of river runoff are formed in the Russian part of the river basin (6.4% of Russian total). Chinese and Mongolian portion is 105.5 km^3 that is 46.2% of additional water resource that comes to Russia from neighboring countries.

The Amur Basin situates within several areas of different geological structure. Its northern and western parts lie on ancient Paleozoic structures of the Mongol-Okhotsk folding system. Mountain ridges are composed of terrigenous-clint-carbonate deposits. Intermountain troughs are filled with much younger rocks. Marine Jurassic sand and slate deposits are covered with continental Cretaceous and Paleogene sandstone and shingle deposits. This territory is characterized with numerous large faults and relatively weakly manifested magmatism. The relief is formed with low- and middle-height mountain ranges and intermountain plains on such overlapping troughs as Upper-Amur, Upper-Bureya, Upper-Zeya and others.

The southern and south-eastern parts of the Amur Basin are situated on the large tectonic structure of North-Manchzhur, Bureya and Khanka massifs, which are parts of fragmented Chinese platform. The horst – the Bolshoi Khingan Range anticlinorium takes the most part of the North-Manchzhur massif. This mountain range is made of Paleozoic and Mesozoic sediments with granite and granodiorite inclusions. Such effusive rocks as quartz porphyries and rhyolites cover vast areas here. Crystalline rocks of the Bureya massif in its western part are overlapped with Cretaceous and Paleogene-Neogene deposits of the Zeya-Bureya intermountain depression. In the rest area they crop out in the form of Proterozoic gneisses, quartzite, slates, phyllites and marbles. Late-Proterozoic and Early-Paleozoic sandstones, slates and limestones are common to the Khanka massif.

The very eastern part of the Amur Basin situates within the Sikhote-Alin folding area, which is an integral element of the East-Asian mobile belt. Highly-dislocated sediment deposits of Jurassic and Cretaceous age are represented with sandstones and slates with numerous intrusions of different composition: from granites to pyroxenites. Effusive beds of porphyries, basalts and andesites are also widely spread. This zone has such huge depressions as Middle-Amur, Udyl-Kisin and Evoron-Chukchagir, which are composed of Paleogene-Quaternary deposits up to 1400 meters thick.

The Amur valley is characterized with a complex structure, formed under specific geological and geomorphological condition. The river runs through or around large mountain massifs and vast lowland territories.

The geological and geomorphological structure of the surface and altitude zonal specifics in humid climate determined the formation of continental mountain and plain natural complexes. These complexes on nearly 20% of the Russian territory suffer noticeable anthropogenic impacts.

Geographical situation and natural condition specifics of the Amur River basin cause wide range fluctuations of river runoff within a year, extremely low water levels in some years, big floods, evident multiyear changes of runoff, multichannel character of the river bed and intensive river bed deformations. In recent decades the impact of different anthropogenic factors increased. These factors include global climate changes as well as hydrotechnical constructions (hydropower dams on the Sungari, Zeya and Bureya rivers, bank enforcements, etc.) and industry and agriculture developments in the Amur Basin.

Viewed from a multiyear perspective the distribution of Amur runoff is irregular. Maximal runoff of 459.2 km^3 (1985) nearly twice exceeds minimal runoff of 250.8 $км^3$ (1979). Values of maximal annual discharge are even more contrast and fluctuate in the range form 15 to 40 thousand m^3/sec. The absolute maximum 65 times exceeds the absolute minimum.

Most of Amur runoff is formed in the Middle-Amur part of about 1 000 km long. Such biggest tributaries as the Zeya, Bureya, Sungari and Ussuri join the Amur here and form 65% of the Amur runoff. In winter three regulated tributaries (Zeya, Bureya and Sungari) form 90% of the Amur runoff. That is why water quality in the lower Amur depends much on Zeya, Bureya and Sungari reservoirs discharge, especially in winter.

Interchange of low water content and high water content periods is quite evident in the Amur water runoff regime. These periods last for 8-15 years. In recent 12 years low water content was observed in the Amur middle and lower reaches. Moreover in 2000, 2001 and 2003 the summer low water level was extremely low, having caused extensive vegetation growth on sand bars, in water-sub-channels and lakes and thus substantial organic matter discharge into Amur water at the end of summer and in autumn.

In general, during the previous century the Amur water content increased by 10-12 %. It happened due to the increase of precipitation in the Amur basin, especially in its lower reaches. In the cold time of the year (November – March) beginning from 1891 to 2003 precipitation increased two times and in the warm time of the year (April-October) precipitation increased 1.22 times (Butova et al., 2004). In general, moisture in the Amur basin in this period increased by 31 %. Still the Amur water content did not increase that much due to the increase of evaporation, caused by the increase of annual average air temperature and a substantial use of Sungari basin water for agricultural developments.

Amur runoff depends much on the regime of permafrost areas, covering vast territories of the northern part of the Amur Basin. In mountainous regions permafrost layers are as 300 meters thick and their temperature is -5 degrees Celsius. These permafrost rocks significantly reduce the underground flow and thus discharge of dissolved substances.

Bogs and swamped areas also play a significant role in river runoff and discharge processes.

Prevailing types of soil in the Russian part of the Amur basin are coarse-humus brown soils, sod alluvial-humus soils and taiga brown soils (the USSR Federal Soil Map, 1988).

According to the soil geographical zoning the Amur basin is a part of a light coniferous taiga of the South-Okhotsk province characterized with a mountain permafrost taiga and mountain rock tundra soils (Liverovsky, Rubtsova, 1962). The soil cover is formed under specific physical and geographical conditions, including deep seasonal ground freezing (up to1.5–2.5 meters) and soil thermal balance unfavorable for the vegetation cover.

A non-frost period lasts 86 days at average. In some years it may be reduced to 64 days. An annual sum of active air temperatures ($t > 10^o$ C) is 1100-1200^o C.

Soil formation specifics in the Amur Basin are as follows:

- soil profile is rather thin and highly detritus;
- vegetation residues are slowly decomposed and result in formation of organic coarse-humus and dry-peat horizons;
- formation of fulvic humus, washed out into the mineral part of the soil profile;
- discharge of alkaline-earth and alkaline elements from the upper horizons into lower horizons under excess moisture and low temperature of relatively short vegetation period;
- filtration capacity of slope grounds is very high.

Brown soils (burozems) are most common (coarse humus burozems, gleysolic burozems and soddy-burozem illuvial-humus soils). Illuvial-humus burozems and taiga and tundra brown soils are less common.

Steep slopes (higher 20^0) are covered with mountain organo-rock debris with a falling type of the profile. Gley soils are formed at the lower parts of the slopes on the debris cones and mountain-foot plains, where inter-soil moisture causes over wetting and reduction conditions.

Recent alluvial and proluvial-alluvial deposits are spread along river and stream valleys. Alluvial soils of different types are formed there.

Humic acids prevail over fulvic acids in humus content of soddy and accumulative horizons of burozems. Due to a high content of organic matter of aggressive fractions of humic and fulvic acids, minerals are rapidly decomposed, form mobile organo-mineral complexes and sediment in the soil profile mostly as iron compounds with aluminum, calcium and magnesium (Makhinova, 1989).

Thus, large amounts of biomass that annually form on the soil cover; intensive inner-soil weathering; abundance of precipitation in combination with a good filtration capacity; input of water-soluble acidifying ions and increased microbiological activities provide highly intensive processes of chemical decomposition of mineral soil horizons and illuvial-humus subtraction of decomposition products. Forest litter decomposition is of north-taiga type that produces organo-peat or organo-soddy horizons with large amounts of aggressive humus substance, like fulvic acids, which are able to form mobile inside-complex ferriferous-humus compounds (Makhinova, 1983).

Alluvial accumulation at average rate of 1.2 mm/year is specific to a 1200 km passage in the Amur lower reaches (Makhinov, 1999, 2006). This process causes mainstream channeling and affects water and river-bed regime. Amur river bed is characterized with a complicated system of sub-channels of different length and moderate depth (5-7 meters). Due to these conditions the main river stream and its bigger channels have specific morphometric characteristics; in particular they are very wide and relatively not deep. Width/depths ratio is usually 400:1 – 500:1. That is why in summer water in these channels is very warm and in autumn water cools quickly and a thick ice cover is formed even if winter atmospheric precipitation is moderate. In some years summer water temperature rises to 26˚C. That is why, the Amur River is the source of warm water supplied to the south-west part of the Okhotsk Sea.

Such morphological characteristics of the river bed cause weak mixing of water masses across the river, especially in winter. For example, in 2005-2006 winter Sungari waters, polluted due to the accident at the chemical plant in the Jilin City (PRC), mixed with Amur water only 370 km from the Sungari juncture down the Amur.

Highly intensive river-bed deformations are the most significant results of alluvial accumulation. River banks are washed out with the rate of 50 m/year, whereas average bank washing out is only 6-12 m/year. The Amur river bed in plain territories is characterized with continuous redistribution of the water flow and sediment deposits between the sub-channels. This process is accelerated in the river passages that suffer multi-factor economic impact (at Khabarovsk and Komsomolsk-on-Amur cities) and in big tributary junctures (Bureya, Sungari, etc). In some river passages water flow redistribution between the cub-channels causes bank washing out even in winter time.

Suspended mater sedimentation in the rivers of the Amur Basin generally depends on geographic regularities. In the Russian part of the Amur Basin the module of sediment discharge changes from 8 to 32 t/ $km^2\cdot$ per year and maximums (20 – 32 t/ $km^2\cdot$ per year) are observed on the Zeya-Bureya plain and in the Khanka Lake Basin. Suspended matter discharge noticeably affects the river discharge of various pollutants and most of all organic substances and heavy metals. Minimal values of the module of sediment discharge (less 10 t/ $km^2\cdot$ per year) are observed in the basins of rivers of the Sikhote-Alin, Badzhal, BolshoiKhingan, etc. mountain ridges.

A large part of the Upper-Amur basin lies in the zone of a low- and middle-height mountain relief with dissections 400-500 meters deep. Steep slopes and abundant strong magmatic and metamorphic rocks determine the formation of big-size fragments. That is why suspended particle discharge in these mountain areas is rather little and mountain rivers remain transparent even in time of floods.

Most amount of terrigenous matter discharge (over 90 %) is formed in the Middle-Amur basin. Big Amur tributaries, which flow through the plain territories, are the main source of suspended matter flow. These rivers are characterized with abundant small-fracture materials such as clay and silt. Highly active river-bed processes in these rivers cause water turbidity increase up to 400-500 mg/l and suspended matter discharge in great amounts.

In the Amur lower reaches bank washing out is coupled with eolian processes, a significant factor of sediment formation. Eolian processes in the Lower-Amur basin have two peaks of intensity: spring and autumn. A spring peak is rather long and lasts from April to June. In April big amounts of eolian materials accumulate on ice and are carried with ice to the river mouth. In spring and early summer, when Amur water level is usually very low, sand bars appear in the river and strong winds blow off lots of sand and dust that sediment in the river.

A general correlation between sediment discharge and water runoff is observed, when multiyear data are analyzed. In 1960-ies sediment discharge was increased, in 1970-ies it was decreased and in 1980-ies it was increased again. As there are insufficient data and no observations of several cycles of suspended matter regularities, it is impossible to reliably describe sediment-behavior trends. Nevertheless, comparisons of sediment discharge in 1960-ies and 1980-ies in the Sungari, when river water content was the same, show that in 20 years water turbidity and suspended matter amount in water increased by 8-10%.

A positive balance of sediments, discharged in the Amur lower reaches and accumulated in the Amur flood-plain and flood-plain lakes, is observed. When the water level in the Amur rises, the turbid river water flows into lakes and lots of river-brought terrigenous material sediment there. Suspended matter in big amounts of up to 20.0 million tons per year sediment in the Lower Amur flood plain during the floods. Just in the Amur passage from Khabarovsk to Komsomolsk-on-Amur up to 5.0 million tons of sediments as average are accumulated per year. Sediments are accumulated in the river-bed, in the river flood-plain and flood-plain lakes formed in the area of Amur tributary junctures. Here coarse suspended matter particles sediment first and thus, down the Amur suspended matter is composed of finer particles.

Small-fraction suspended matter discharge into the Amur estuary produces a negative effect on the river delta formation. Discharge, downward and tidal currents in the Amur estuary and the Tatar Strait are characterized with a complex interchange of directions and high velocities that exceed the velocity of the Amur River in its lower reaches. As the Amur estuary and liman are rather shallow, wind-driven waves during the storms accelerate bottom sediment suspension and discharge into the open sea.

Ice also plays an important role in transporting bottom sediments in the Amur estuary and the Tatar Strait. The mechanism of terrigenous material inclusion into the ice cover is rather intensive in shallow areas, sand banks and at the shores of the Vospry and Oremif islands, the only elements of the over-water Amur delta. Concentrations of ice-frozen terrigenous materials reach 10 kg/m^3 (Makhinov, Ivanov, 2001). Transportation of bottom sediments with ice provides a stable balance between inflow and outflow of terrigenous material in the Amur estuary.

Although natural landscapes in the Russian part of the Amur Basin underwent minor changes, the contrast between the extreme parameters of the main hydrological characteristics has increased. Fluctuations of water level and discharge, water turbidity and sediment diposits were found to increase in resent years. River-bed processes have also accelerated. Due to these factors the Amur discharge of water and dissolved and terrigenous substances into the

Okhotsk and Japan seas becomes more unstable and uneven.

Anthropogenic impacts on the Amur Basin ecosystems are coupled with natural dynamics, affected by global climate changes. However, recent changes of natural environment of the region are studied insufficiently. That is why, studies of Amur water runoff and discharge of sediment, dissolved and organic substances, as well as their impact on marine ecosystems seem quite urgent and important.

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